Short communication

Direction of gaze effects on early face processing: eyes-only versus full faces

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Accepted 2 August 2000

Abstract

The N170 event-related potential (ERP) reflects an early stage of face processing. We wished to determine if it would also index the intuitively important information provided by direction of gaze. Two studies were run. In one, stimuli included full faces with the eyes looking forward, to the left or closed; in the other study the stimuli included eyes-only, looking forward, left or closed. Gaze direction had no effects on amplitude, but longer latencies were found for faces with eyes closed. With eyes-only stimuli, more marked effects on latencies and borderline effects on amplitudes were seen. We suggest that there can only be limited evidence of gaze-specific sensitivity in ERP studies in humans, without eye movement. © 2001 Elsevier Science B.V. All rights reserved.

Theme: Neural basis of behavior

Topic: Cognition

Keywords: Direction of gaze; Event-related potential; N170; Vision

Direction of gaze has considerable importance as a social cue and in communication between individuals, as well as offering critical information about another’s direction of attention. Researchers have investigated the influence of direction of gaze from behavioural to physiological indices, with studies including non-human primates, human infants, adults and patient populations (e.g., Refs. [7,11–15,17,19]). In pivotal studies in primates, researchers found that cells in the temporal cortex were sensitive to faces, and in particular, to the direction of gaze [19]. However, despite suggestions in the literature that studies have shown specialised detectors for eyes and gaze direction in humans [13], data are scarce in either scalp or intracranial event-related potential (ERP) recordings. Studies have shown that the posterior temporal cortex in humans has cells sensitive to faces (e.g., Ref. [18]), but gaze was not manipulated. ERPs to faces can also be recorded from discrete cortical areas in humans [1,3] and in an intracranial study that manipulated gaze, McCarthy et al. [17] found that although there was a tendency for the faces with eyes facing forward, or mutual gaze, to show smaller ERPs (N200) than faces with eyes averted or closed, these effects did not reach significance.

The above studies, however, used full faces, with direction of gaze modified within the faces. We hypothesised that if only eyes were presented, thus removing all other facial features, we would see the direction of gaze influences on the recorded ERPs. It has also been shown that the scalp recorded N170 is larger to eyes-only stimuli than to full faces [5,9], and thus may be more sensitive to manipulations of direction of gaze if eyes-only stimuli are presented.

Thirty adults participated in the study; three had too few noise-free trials, thus the data from 27 were analysed (mean age: 24.4±3.0 years; 14 females). Two studies were run. In the first, grey-scale photographs of faces (face task) (Fig. 1a) were presented in the following categories:
Fig. 1. Examples of the stimuli used in the face (a) and eye (b) tasks. For the face task (a), examples of a face with eyes forward, face with eyes averted, face with eyes closed, scrambled face, flower and checkerboard target. For the eye task (b), examples of eyes closed, eyes forward, eyes averted, scrambled eyes, lips and the checkerboard target.
eyes averted to the left, phase-scrambled faces and pictures of flowers. These stimuli were from the same series used by McCarthy et al. [17] (see their Fig. 9). For the second study (eye task), the eyes from the above faces were cut out from the three categories of faces and scrambled faces using a standard sized rectangle (Fig. 1b). Lips were also taken from the same faces, cropping with a slightly smaller rectangle. Thus, the stimuli consisted of eyes looking forward, looking left, closed, scrambled eyes and lips (Fig. 1b). A total of 336 stimuli were presented in each study, without repetitions apart from the target stimulus, which was a checkerboard (probability = 0.14); subjects made a button press to targets. Stimuli were presented for 400 ms with an ISI of 1.8–2.2s. Short pauses of a few minutes were given between tasks; the order in which the tasks were presented varied across subjects.

ERPs were recorded from 29 electrodes in an ECI electrode cap. An averaged reference montage was used, with Cz as the reference lead; the average reference was calculated off-line. ERPs were recorded for 1 s, with a 50 ms pre-stimulus baseline, and a bandpass of 0.1–100 Hz, with a NeuroScan system and SynAmps. Trials were rejected for EOG or movement artefact (>±150 μV), baseline corrected and then averaged according to the stimulus categories. ERPs evoked by the checkerboard stimuli were not analysed, as they were included only to provide a task for the subjects – to maintain attention. For both tasks, the components of interest were N170, measured at the posterior-temporal electrodes, P7, P8, P9 and P10, and the frontal positivity (VPP [16]) measured at Fz, both within a 135–220 ms window (Fig. 2a,b). The data were analysed using repeated measures analyses of variance (with Greenhouse–Geisser adjusted degrees of freedom) for the five categories of stimuli in each task, sex and hemisphere (collapsing across electrodes P7 and P9 (LH), and across P8 and P10 (RH)), for N170 amplitude.

![Fig. 2](image_url)

Fig. 2. Grand average ERPs to the five categories of stimuli in the faces task (a) and in the eye task (b) at the electrode sites Fz, P7, P8, P9 and P10. The VPP is indicated by an arrow at Fz and N170 at P10.
and latencies. For VPP repeated measures of latency and amplitude were analysed as a function of stimulus and sex.

For the face task there were significant latency differences across categories of stimuli ($F(1.9, 48.3)=21.88, P<0.0001$), as the flowers and scrambled faces had longer latency N170s, and for sex ($F(1, 25)=6.48, P<0.017$) due to longer latencies in males (166 ms in males vs. 154 ms in females). A stimulus by electrode effect ($F(2.3, 57.9)=9.01, P<0.0001$) was due to longer latencies over the right hemisphere electrodes for the face stimuli and the opposite pattern for the control stimuli (Fig. 3a). Amplitude effects ($F(2.2, 55.1)=70.52, P<0.0001$) were due to much smaller N170s for the flowers and scrambled faces and an electrode effect ($F(2.1, 52.8)=7.77, P<0.001$) due to larger amplitudes at the inferior (P9, P10) than superior (P7, P8) electrodes, particularly for the right hemisphere sites (Fig. 4a). This electrode effect was not seen for the scrambled face stimuli, however, yielding an electrode by stimulus interaction ($F(4.1, 103)=3.34, P<0.012$). When only the three categories of face stimuli were analysed there were no effects on amplitude, but there was a latency effect ($F(1.6, 41.9)=5.05, P<0.015$), due to a slightly longer latency for the faces with eyes closed (Table 1; Fig. 3a).

For the VPP in the face task, effects of stimulus were driven by the consistently longer latencies for the lips and for sex ($F(2.6, 65.5)=7.19, P<0.001$) due to longer latencies for the flowers, and amplitude ($F(2.7, 68.6)=44.3, P<0.0001$) due to much smaller amplitudes for the scrambled face and flower stimuli (Table 1). There were no differences in VPP amplitudes or latencies among the three face stimuli.

For the eye task, there were significant latency effects for stimulus category ($F(2.2, 55.9)=18.70, P<0.0001$) driven by the consistently longer latencies for the lips and for sex ($F(1, 25)=10.99, P<0.003$), due to longer latencies for males (189 ms in males; 174 ms in females). There was an effect of hemisphere on the eye stimuli ($F(1, 25)=9.75, P<0.004$) due to slightly longer latencies over the right hemisphere sites (Fig. 3b) and a hemisphere by sex interaction ($F(1, 25)=5.34, P<0.029$), as this...
asymmetry was evident only in the females. For N170 amplitude in the eye task, there were significant effects of stimulus ($F(3.2, 80.8)=56.43, P<0.0001$) driven by smaller amplitudes for the lips and particularly scrambled eyes (Table 1; Fig. 4b). An electrode effect ($F(1, 25)=15.12, P<0.001$) was due to larger amplitudes at the inferior electrodes, and a stimulus by electrode interaction ($F(2.2, 55.3)=11.54, P<0.0001$) was due to this effect not being present for the scrambled eyes (Fig. 4b). The amplitudes were generally larger over the right hemisphere sites ($F(1, 25)=6.56, P<0.017$) but this did not interact with the category of eye stimulus. When only the three eye stimuli were analysed there remained an effect on N170 latency ($F(18, 45.1)=31.54, P<0.0001$) due to longer latencies for eyes closed (Table 1), and a trend for smaller amplitudes ($F(1.8, 44.7)=2.68, P<0.08$) also for eyes closed (Figs. 3b and 4b). There were no significant differences in amplitude or latencies between eyes forward and eyes averted.

For VPP in the eye task, stimulus effects were seen on latency ($F(2.4, 59.7)=12.3, P<0.0001$), driven by the much longer latencies for the lips, and amplitudes ($F(3.2, 80.7)=21.49, P<0.0001$) due to smaller amplitudes for the control stimuli (Table 1). When VPP was analysed including only the three eye stimuli there were significant effects for both latency ($F(1.5, 39.4)=5.68, P<0.01$) and amplitude ($F(1.6, 39.7)=4.32, P<0.03$) due to slightly longer latencies and smaller amplitudes for the eyes closed.
These data show that the effect of direction of gaze is subtle in the early stages of processing of face stimuli. Although significant effects were seen with latencies in both the face and eye tasks, when only the eyes are shown, such that the direction of gaze is the only information in the stimuli presented, the differences between stimulus categories was larger. This greater sensitivity with eyes-only stimuli is likely also due in part to the lateral surface of the temporal lobes being more sensitive to face parts than to whole faces, and more responsive to changeable aspects of these face parts, such as gaze or movement (i.e., Refs. [17,21]). Consistent with earlier studies [5,17,24], eyes yielded longer N170 latencies than did full faces, and lips had even longer latencies than did eyes, and relatively little latency difference but marked amplitude differences were seen between control and face stimuli [3]. Also in accordance with earlier studies, N170 showed greater sensitivity to manipulations of the face stimuli than did the VPP [6,22], although it was not the case in this study for the eye stimuli. The sex difference is similar to that found in other ERP studies of faces [9,24], but larger than what would be expected from average differences in length of pathway between the sexes [4]. This suggests that females are faster
Table 1
N170 and VPP latencies (in ms) and amplitudes (in µV) by stimulus category (standard error in parentheses)

<table>
<thead>
<tr>
<th>Stimulus category</th>
<th>N170 latency (ms)</th>
<th>N170 ampl. (µV)</th>
<th>VPP latency (ms)</th>
<th>VPP ampl. (µV)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Face task</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Faces, eyes forward</td>
<td>155 (2.4)</td>
<td>−7.13 (0.63)</td>
<td>154 (2.3)</td>
<td>3.39 (0.42)</td>
</tr>
<tr>
<td>Faces, eyes averted</td>
<td>155 (2.3)</td>
<td>−7.12 (0.57)</td>
<td>153 (1.9)</td>
<td>3.41 (0.49)</td>
</tr>
<tr>
<td>Faces, eyes closed</td>
<td>158 (2.7)</td>
<td>−7.09 (0.64)</td>
<td>156 (2.7)</td>
<td>3.07 (0.54)</td>
</tr>
<tr>
<td>Flowers</td>
<td>171 (2.9)</td>
<td>−2.48 (0.47)</td>
<td>165 (3.3)</td>
<td>0.31 (0.49)</td>
</tr>
<tr>
<td>Scrambled faces</td>
<td>161 (2.8)</td>
<td>−1.16 (0.40)</td>
<td>156 (3.1)</td>
<td>−0.56 (0.49)</td>
</tr>
<tr>
<td><strong>Eye task</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eyes forward</td>
<td>173 (2.3)</td>
<td>−7.33 (0.54)</td>
<td>175 (2.7)</td>
<td>3.09 (0.40)</td>
</tr>
<tr>
<td>Eyes averted</td>
<td>174 (2.5)</td>
<td>−7.48 (0.62)</td>
<td>172 (2.7)</td>
<td>3.06 (0.49)</td>
</tr>
<tr>
<td>Eyes closed</td>
<td>184 (2.2)</td>
<td>−6.75 (0.58)</td>
<td>181 (2.8)</td>
<td>2.03 (0.38)</td>
</tr>
<tr>
<td>Lips</td>
<td>200 (4.6)</td>
<td>−5.13 (0.57)</td>
<td>195 (4.6)</td>
<td>0.80 (0.46)</td>
</tr>
<tr>
<td>Scrambled eyes</td>
<td>174 (4.0)</td>
<td>−1.69 (0.42)</td>
<td>172 (3.7)</td>
<td>−0.17 (39)</td>
</tr>
</tbody>
</table>

at processing facial stimuli, which may contribute to reported behavioural differences (e.g., Ref. [8]), and attributes the increased speed to early stages of processing.

Shifts in direction of gaze produce covert shifts of attention [12,13] and greater activation in the intraparietal sulcus [14], suggesting a spatial attentional component with differing eye gazes, as postulated by several researchers [13,17,25]. This attentional shift may not be reflected in the early ERP component measured here because it occurs at a longer latency, or because the N170 is resistant to attentional influences [23]. The present finding of no effects between mutual and averted gaze is not likely due to insufficient power, however, as compared to other neuroimaging studies on direction of gaze, we had a large number of subjects.

In intracranial studies, direction of gaze produced no significant latency or amplitude effects [17] and the current scalp recordings show longer latencies only to stimuli with eyes closed compared to stimuli with eyes forward or averted. No differences were seen in N170 or VPP between eyes forward and eyes averted in either task. The longer latency for faces with eyes closed in the present study or eyes absent [10] could be due to longer processing being required for sub-optimal views of a face [17] or to faces with closed eyes being less salient or important stimuli.

Although some neuroimaging studies have shown no difference between direct and averted gaze [25], others have [14,20], but effects seen in PET or fMRI studies may reflect slower, later processes than those investigated here. Wicker et al. [25] found both mutual gaze and averted gaze produced increased blood flow in the right superior temporal cortex compared to an eyes down (no gaze) condition. They suggested that this region was the human analogue of the superior temporal sulcus (STS) in monkeys, which contains cells that are responsive to direction of gaze [19] and which is implicated in gaze detection tasks [7]. Hoffman and Haxby [14] found that presenting faces in which direction of gaze was varied showed greater fMRI activation of the STS than faces where gaze was always forward. For their task, however, the faces were presented rapidly (two per second) and the effect of having the direction of gaze varying from face to face may have produced a comparable effect to that obtained by Puce et al. [20] when they investigated moving eyes. The STS activation may be related to apparent movement of eyes or shifting of direction of gaze [2,20]. When recording ERPs to facial movement, Puce et al. [21] found larger responses to eyes moving away from the viewer, and also suggested that the lateral temporal cortices are part of a system sensitive to biological motion [2], such as facial movements, and particularly eye movements. As we have shown in the present study, there is no effect on N170 between forward and averted gaze without movement.

Thus, several converging neuroimaging studies propose that the STS is activated by direction of gaze. This region of the human brain is not accessible in intracranial surface recordings nor would lateral scalp recordings be sensitive to activity in this region, which is within a sulcus and would produce a vertical dipole. This may well explain the lack of significant effects in either intracranial or scalp studies between direct and averted gaze, in components (N170, N200) that are otherwise very sensitive to face stimuli. If the main locus of analysis of gaze is in the STS, related to the movement of eyes when the direction of gaze shifts, it is unlikely to be detected by surface ERPs unless there are associated eye movements. Thus, despite the intuitive importance of gaze direction, there can only be limited evidence of gaze-specific sensitivity in neurophysiological studies in humans when static images are presented.

References


